A Consortium for Ocean Circulation and Climate Estimation

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LONG-TERM GOALS

The project aims to advance ocean data assimilation into a quasi-operational tool for studying ocean circulation. Observing the complete state of the ocean is difficult owing to its turbulent nature and to the sparseness and limitation of extant measurements. This project will establish a routine description of the global ocean by optimally combining available observations using a general circulation model, to monitor, to assess, and to understand ocean circulation. The effort further aims to demonstrate the practical utility of ocean observing systems by developing applications of such syntheses.

OBJECTIVES

The project's central technical goal is to establish a complete global ocean state estimation over the 16-plus year period from 1985 to present at 1/4º resolution with complete error descriptions, combining all available large-scale data sets with a state-of-the-art general circulation model. Of particular interest is understanding processes underlying the recent 1997-99 El Niño/La Niña event and the possible shift in the Pacific Decadal Oscillation in 1999. Tools necessary for such synthesis will be advanced, including improvements in models and assimilation techniques, with an emphasis on devising practical solutions in marshaling diverse data sets and large numerical models on a routine basis. The effort will exploit existing and ongoing oceanographic experiments (e.g., WOCE) and satellite missions (e.g., Jason-1) and will support planned experiments including the Climate Variability and Predictability Program (CLIVAR) and the Global Ocean Data Assimilation Experiment (GODAE).

APPROACH

Advanced data assimilation schemes and state-of-the-art numerical ocean general circulation models are employed to analyze global oceanographic observations. The model is based on a parallel version of the MIT ocean general circulation model (Marshall et al., 1997) that exploits massively parallel supercomputers. The present model extends from 80°S to 80°N with a fairly high resolution (1° by 0.3° within the tropics, with 10m near surface layers) and employs advanced mixing schemes to best simulate diabatic processes. A hierarchical assimilation system is devised for computational efficiency that consists of a Kalman filter and smoother (KFS), the adjoint method, and a Green's function method. The approach is characterized by the physical consistency of its solution's temporal evolution (Fukumori, 2003a). I.Fukumori, T.Lee, and D.Menemenlis are technical leads in the KFS, adjoint, and Green's function assimilations, respectively. L.Fu is responsible for programmatic oversight, and V.Zlotnicki is investigating high-frequency ocean bottom pressure variations. This project is part of a larger consortium formed under the National Oceanographic Partnership Program (NOPP). The synergistic efforts of the consortium elements are described below ("RELATED PROJECTS.")

WORK COMPLETED

A hierarchical assimilation system has been established for producing routine analysis of ocean circulation. A series of Green's function are computed to correct gross errors in the model's time-mean state; an approximate Kalman filter and smoother (Fukumori, 2002) are employed to produce near real-time, routine analysis of the time-evolving state; the adjoint method is utilized to periodically further optimize the state estimates. Satellite and in situ observations are assimilated covering the period from 1993 to present (September 2003) that include sea level (satellite altimetry), temperature and salinity profiles (hydrography), and sea surface winds (satellite scatterometry). Near real-time analyses are updated approximately every ten days and representative plots of the state are illustrated at http://ecco.jpl.nasa.gov/external/ (Figure 1). A data server (Live Access Server at http://www.ecco-group.org/las/main.pl) (Figure 1) provides access to the entire analyses to the general oceanographic community.

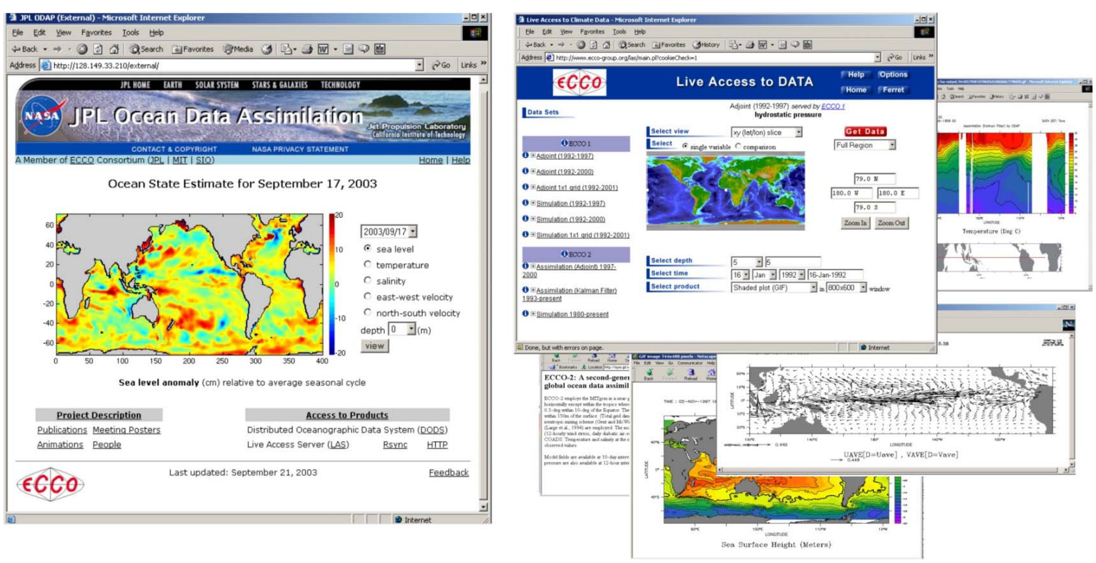


Figure 1: (Left) ECCO near real-time analysis at http://ecco.jpl.nasa.gov/external, (Right) ECCO Data Server at http://www.ecco-group.org/las/main.pl.

RESULTS

ECCO's data assimilated global ocean circulation estimates are analyzed to study mechanisms of seasonal-to-interannual changes of the ocean. For instance, Lee et al. (2003) has discovered that variability in the tropical-subtropical exchange in the Pacific Ocean pycnocline is anticorrelated between transport through the interior of the ocean and that by way of the low latitude western boundary current (Figure 2). The anti-correlation is in contrast to the time-mean circulation in which both transports are towards the equator. The tropical-subtropical exchange contributes to defining the state of the tropical ocean, and its variability in the interior is hypothesized as causing decadal changes in the tropical Pacific (e.g., McPhaden and Zhang, 2002). Results of Lee et al. (2003) illustrate the importance of monitoring the entire state of the ocean, such as provided by an assimilation system, as opposed to an observation of one element alone (e.g., measurement of interior transport).

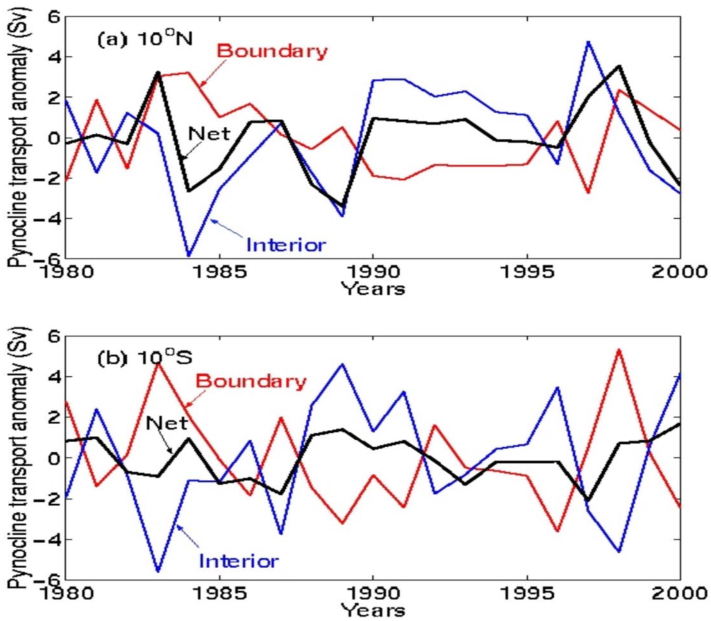
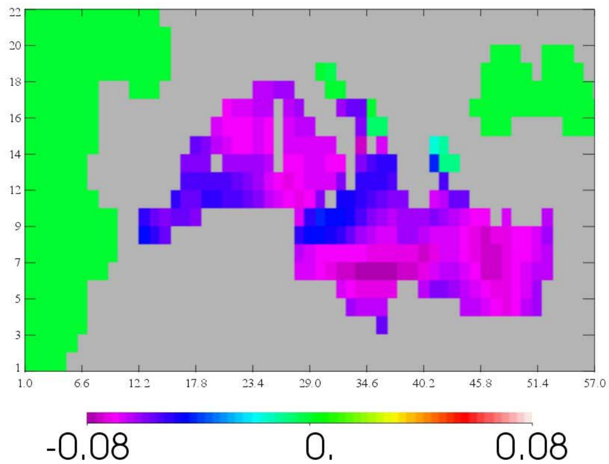


Figure 2: Anomaly time series of tropical-subtropical meridional pycnocline transport in the Pacific Ocean along 10°N (top) and 10°S (bottom). Transport in the low latitude boundary layer (red) is out of phase with and partially compensate that in the interior (blue). (From Lee et al. (2003).)



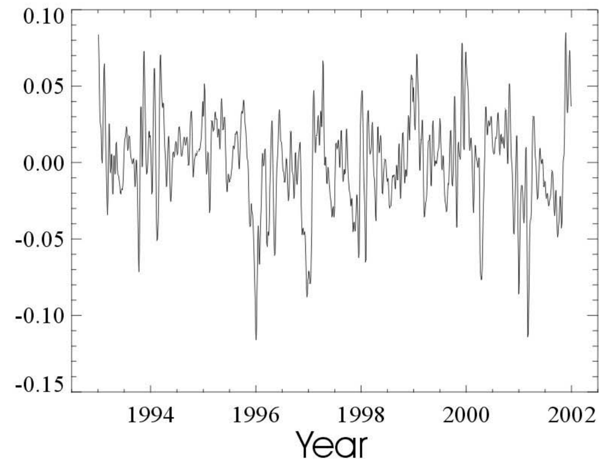
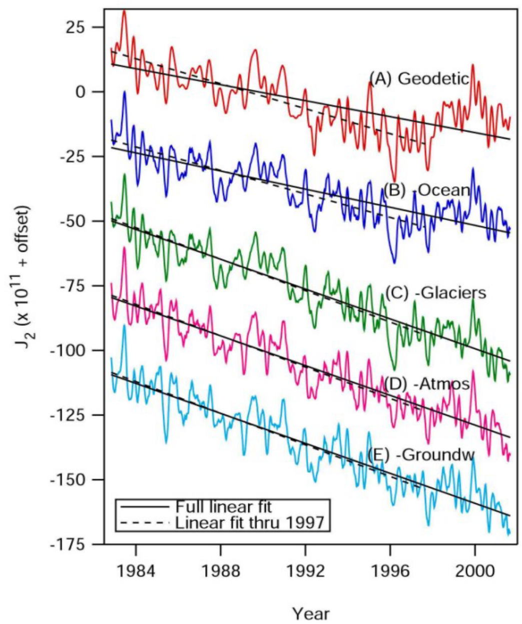


Figure 3: (Left) First empirical orthogonal function (EOF) of non-seasonal Mediterranean Sea sea level variability, (Right) Amplitude time-series of the first EOF. (From Fukumori (2003b).) [The first EOF is nearly uniform over the Mediterranean Sea with variability at periods of 10s of days to several months.]

A new mode of sea level variability has been discovered in the Mediterranean Sea (Fukumori, 2003b). Nearly 50% of the non-seasonal sea level variability in the Mediterranean Sea can be attributed to a fluctuation that is nearly uniform across the basin with a period ranging from 20-days to several months and with an amplitude as large as 10 cm (Figure 3). Corresponding model estimates suggest that this mode is barotropic and is associated with changes in net mass transport through the Strait of Gibraltar caused by winds in the vicinity of the strait. Accurate modeling of this mode will lead to improved prediction of sea level fluctuation in the Mediterranean Sea that is important especially in low lying coastal regions.

The ocean analyses are also employed in geodetic studies to help explain various changes that are observed. Such applications also provide unique integral measures of the goodness of the ocean data assimilation system and, in turn, can potentially improve the accuracy of the estimates themselves. For instance, the Earth's dynamic oblateness (J2) has been decreasing due to postglacial rebound. However, J2 began to increase in 1997, indicating a pronounced global-scale mass redistribution within Earth's system (Cox and Chao, 2002). Using, in part, the ECCO ocean circulation estimates, Dickey et al. (2002) determined that the observed increases in J2 are caused primarity by a recent surge in subpolar glacial melting and by mass shifts in the Southern, Pacific, and Indian Oceans (Figure 4). Moreover, the data assimilated ocean model was found to be in closer agreement with the observed J2 variations than a model without data is, demonstrating the accuracy of the data assimilation system.



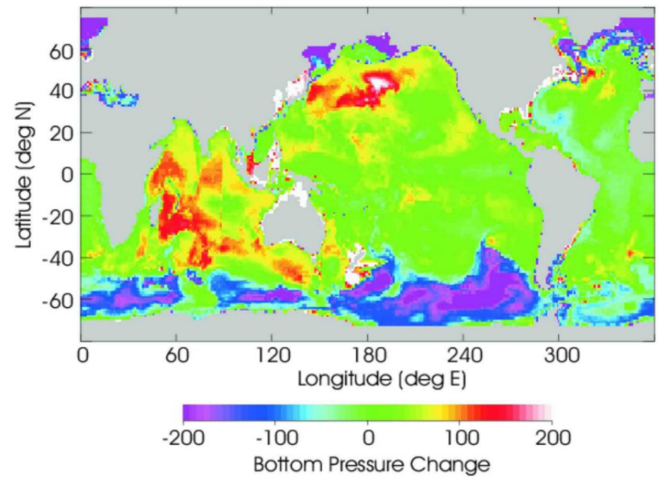


Figure 4: (Left) Earth oblateness (J2) observations (red curve labeled A) and residuals obtained by successive removal of the source terms. Removal of the ocean estimate (blue curve labeled B) accounts for 42% of the nonlinear change in J2. (Right) Change of average ocean bottom pressure between 1996-97 and 1999-2000. (Both from Dicky et al. (2002).) [Ocean bottom pressure decreases in the Southern Ocean and incrases in the Indian Ocean and the North Pacific Ocean.]

IMPACT/APPLICATIONS

Data assimilation's regular and complete description of the ocean facilitates a wide range of studies in ocean circulation and its applications. This is because it is difficult to make inferences about the ocean continuum from individual measurements without knowledge of the surroundings. Processes controlling the state of the ocean and its evolution can be diagnosed and monitored to help detect and anticipate climate variability. Descriptions of ocean circulation also help understand and quantify the carbon cycle and other biogeochemical processes of the ocean that are affected by advection and mixing (see "TRANSITIONS" below.) Data assimilation contributes to practical applications of oceanography that require complete descriptions of the time evolving flow field and thermal structure such as fishing, shipping, search and rescue, industrial and naval operations, and weather forecasting. Model-data syntheses also help identify sources of model inaccuracies, providing an objective basis for ocean model improvement. Additionally, data assimilation helps in the design of optimal observing systems by quantifying impacts of different observing strategies on the accuracy of the syntheses.

Finally, the assimilation system itself (adjoint and Kalman filter and smoother) provides a versatile tool for other applications. The assimilation system can be employed to assimilate other data types and/or applied to other configurations including regional and biogeochemical studies. The MIT general circulation model can also be converted to an atmosphere model, and thus provide a system for atmospheric and/or coupled ocean-atmosphere data assimilations. Application of the model adjoint to sensitivity studies is an emerging area of investigation that provides new insight into the workings of complex systems.

TRANSITIONS

The ocean circulation estimates resulting from this project are being utilized by several external investigators in various applications. These include investigation of the uptake and transport of biogeochemical tracers (carbon, oxygen, nitrogen, and nutrients) (M. Follows, MIT; J. Randerson, Caltech), carbon-cycle modeling (N. Gruber, UCLA; C. LeQuere, MPI, Germany), studies of the effects of ocean circulation on earth rotation (R. Gross, JPL), and changes in Earth's gravity field (J. Dickey, JPL).

Within the ECCO consortium (see "RELATED PROJECTS"), this effort has helped early development of the parallel MIT ocean circulation model and has spearheaded the creation and application of its adjoint. Experience gained from exploring the synergism between the adjoint and KFS approaches helps advance the consortium's complementary investigations.

RELATED PROJECTS

This project is part of a larger consortium formed under the National Oceanographic Partnership Program (NOPP). The consortium, entitled "Estimating the Circulation and Climate of the Ocean" (ECCO; http://www.ecco-group.org) consists of groups at the Scripps Institution of Oceanography (SIO; D. Stammer, PI), Massachusetts Institute of Technology (MIT; J. Marshall, PI), and the present effort at JPL. The MIT group is the lead in forward model development, while SIO and JPL are leads in data assimilation. Assimilation efforts at SIO and JPL are closely linked and are synergistic. The focus of the SIO group is on optimal assimilation utilizing a comprehensive set of observations whereas the JPL group is focusing on high resolution near real-time analyses. The trade-off between optimality and scope is justified given present limitations in computational resources. The two approaches will merge as knowledge and experience is gained by the complementary studies and as additional computational resources become available.

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